INDOOR AIR POLLUTION IN DEVELOPING COUNTRIES

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Air pollution in general and indoor air pollution in particular have been associated in many people's mind with industrialization and urbanization and, thus, with the cities of developed countries where most of the measurements have been made. Recently, however, the UNEP/WHO Global Environment Monitoring System (GEMS)[e] has demonstrated quite convincingly that the worst ambient conditions reported today obtain in the cities of developing countries. In a similar fashion, although most studies of indoor air quality have been carried out in developed-country buildings, for many important pollutants the largest indoor-pollutant concentrations and exposures are also found in the developing countries in both rural and urban households.

Worldwide, there are four principal classes of indoor pollutants *(1)*, those derived from:

(i) combustion, e.g. carbon monoxide, particulates, and sulfur and nitrogen oxides from cooking stoves, space heaters and cigarettes (environmental tobacco smoke–ETS);
(ii) building materials, furnishings and chemical products, e.g. pesticides, volatile organic compounds, formaldehyde;
(iii) the ground under the building, i.e. radon;
(iv) biological processes, e.g. mold, mildew, mites.

As with ambient emissions, the impact of indoor emissions on concentrations depends directly on ventilation (airflow and mixing volume). In general, most housing in developed countries lies in temperate latitudes and thus has relatively low air exchange rates, i.e. typically one air change per hour or less. Under these conditions, even rather small emission rates can result in indoor concentrations that exceed those outdoors, considering also that indoor air quality is affected by outdoor levels. Since people spend a great proportion of time indoors, typically 90% or more, indoor pollution is frequently the predominant factor in total exposure.

In the developing world, however, much housing lies in tropical and subtropical regions and typically has much higher ventilation rates. In these circumstances, it takes fairly high emission rates to produce significant pollutant levels. Unfortunately, there seem to be many situations in which such strong indoor sources exist. Moreover, in spite of being a minority, several hundred million people in developing countries require space heating for a significant part of the year, and thus share with developed countries the difficult trade-off between space-heating fuel efficiency, ventilation and indoor air quality.

This review focuses on indoor combustion-derived pollutants, principally because comparatively little work has been published on the other three categories in developing countries. Although the main purpose is to review the available epidemiological studies, the relevant sources and pollutants will be briefly discussed first.

Indoor sources

Due to the generally higher ventilation rates, ETS has not been singled out in developing-country studies to date. With the alarming increase in smoking rates and the changing housing stock in some developing countries, however, such research may well be warranted. Although such minor combustion sources as incense and mosquito coils have occasionally been examined, most efforts have concentrated on cooking and heating stoves.

After tobacco, the most common indoor pollution source of concern in developed-country studies has been gas cookstoves. In the global context, however, gas stoves are near the upper end of an evolution in the quality of household fuels, sometimes called the energy ladder *(2)*. Although dependent on local conditions, at the lowest rung might lie those households that rely on dried animal dung and scavenged twigs and grass for cooking. The next step might be crop residues, followed by wood, and then charcoal. The first non-biomass fuel might be kerosene, as in India, or coal, as in China. Highest on the ladder lie bottled and piped gases and, for some rich communities, electricity. In general, each step involves an increase in the cooking system's levels of technology, cleanliness, efficiency and cost.

On a global scale, it is estimated that more than half of the world's households cook daily with unprocessed solid fuels, i.e. biofuels or coal. An unknown, but significant, proportion of this activity takes place in conditions where much of the airborne effluent is released into the living area. Although ventilation rates are often relatively high, the emission factors for such fuels are so great that indoor concentrations and exposures can be quite significant. Compared with gas stoves, for example, even stoves using one of the cleaner biofuels, wood, typically release 50 times more pollution in cooking an equivalent meal *(2)*.

Although less prevalent, space heating with unprocessed solid fuels can also lead to high indoor air-pollution levels. For part of the year in the high-altitude areas of developing countries in all four major regions (Asia, Africa, Latin America and Oceania), unvented space heating with biomass fuels is common. In addition, in much of temperate China,

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[e] Global Environment Monitoring System. *Assessment of urban air quality*. United Nations Environment Programme/World Health Organization, 1988 (Unpublished document).

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significant indoor concentrations result because of the high emission rates of coal fuels in simple stoves, although the pollution is less serious with venting, as is the case in most Chinese cities.

It is impossible at this point to derive a reliable estimate of the total developing-country population exposed to what might be termed "excessive" indoor concentrations, partly because there are few internationally-recognized standards for household concentrations. Assuming that they would be at least as stringent as outdoor standards, the total number of people exposed clearly rivals or exceeds that exposed to excessive ambient concentrations in all the world's cities,* i.e. several hundred million. Given the greater time spent indoors and the known magnitude of concentrations in many situations however, the total global dose-equivalent (amount actually inhaled) is probably higher for some important pollutants, e.g. particulates *(3)*. Pinpointing the actual sources of exposure is further complicated in many urban and even some rural areas, because indoor concentrations are influenced by outside as well as inside sources.

Pollutants

In spite of the long history of fascination with fire and hundreds of years of scientific effort, the ability to predict the detailed behaviour of combustion in any but the simplest configurations of fuel and air has eluded us. Nevertheless, empirical evidence has shown that unprocessed solid fuels produce hundreds of chemical compounds because of the incomplete combustion that occurs under the operating conditions of simple cookstoves, which are often little more than three-rocks or a small open-ended box of clay. Both coal and biomass act this way, although the mix of compounds from each is significantly different. Unlike coal, biomass generally contains few intrinsic contaminants, such as sulfur, trace metals and ash, and thus can, under proper conditions, be burned with no releases other than the products of complete combustion, i.e. carbon dioxide and water. Unfortunately, it has turned out to be difficult to reliably create these conditions in modestly-priced household devices.

As with tobacco smoke, which is also the result of open biomass combustion, such cookstove smoke is a complicated mixture of aerosol (droplets and solid particles) and gases. Biomass smoke contains significant amounts of several of the important pollutants, for which most countries have set standards: carbon monoxide, particulates, hydrocarbons and, to a lesser extent, nitrogen oxides. Perhaps more important however is that the aerosol contains many organic compounds that are thought to be toxic, carcinogenic, mutagenic or otherwise worrisome *(4)*. Coal smoke contains all this plus additional pollutants, e.g. sulfur oxides, inorganic ash particles and heavy metals such as lead. It is difficult to make generalizations about the relative amounts of each kind of pollutant however, because emissions can change with relatively small changes in fuel quality, configuration and combustion, and comparatively little detailed research has focused on such conditions.

*For a review of exposure studies related to biomass, see reference *(4)*; for those examining coal, see reference *(6)*.

Epidemiology

Although, by international comparison, the exposures received in households in many developing countries are large, epidemiological studies are still difficult. Expected short-term (acute) effects, such as acute respiratory infections (ARI), have many other important risk factors, some of which correlate with pollution exposures. Long-latency effects, such as cancer and chronic obstructive lung disease (COLD), also involve other risk factors. Moreover, it is difficult to associate these effects with previous exposures because of the long interval between these exposures and the onset of illness (the appearance of symptoms) *(5)*. Physiological and biochemical markers, such as lung function and immunological status, are only indicators of the particular pathology.

For the sake of conciseness this review focuses on developing-country studies published since 1980 and which include a health-related endpoint. Most of the early studies are cited, but not discussed in detail, and purely environmental studies are only mentioned occasionally, i.e. those that looked only at exposures.† The studies have been divided according to general category of source, biomass or coal, and the health-related endpoint being examined. Most have been done either in South Asia with rural populations using biomass, or in China with urban groups using coal.

Biomass – South Asia, Africa, Guatemala and Papua New Guinea

The vast majority of rural inhabitants in these parts of the world use unprocessed biomass fuels. Although significant in some communities, the utilization of these fuels in cities has been dropping as households move up the energy ladder, i.e. to kerosene and bottled gas. Proportionately, household coal use is minor, but it involves tens of millions of people and seems to be on the increase as the availability of biomass fuels dwindles and petroleum fuels remain relatively expensive.

Carboxyhaemoglobin (HbCO). In a study of carbon monoxide (CO) concentrations in 180 biomass-burning kitchens of two Guatemalan villages at different elevations (250 m and 1 350 m), Dary et al. *(7)* also determined HbCO blood concentrations in women. They found lower HbCO levels in women cooking in well-ventilated kitchens, but no difference in concentrations between houses having similar ventilation but situated at different altitudes.

In both well-ventilated and poorly-ventilated kitchens, however, there were higher HbCO levels in the higher-altitude village, with blood reaching 3.5% HbCO in some women as a result of concentrations of 30-50 ppm during the cooking period. In other words, at the same CO concentration, exposures at higher elevations produced higher HbCO levels, a finding consistent with known physiological mechanisms and a significant consideration in those many high-altitude areas of the developing world where solid fuels are burned for space heating without ventilation.

Lung function. To test for the effect of domestic smoke, Pandey et al. *(8)* used a dry portable spirometer to measure lung function in a random sample of 150 women aged 30-44 years living in a rural area on the outskirts of Kathmandu valley at an elevation

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of 1 600 m. The area is totally free from industrial and atmospheric pollution and women spend considerable time near the hearth, which is used for both cooking and heating. Smoke concentrations are high because dwellings are ill-ventilated and without chimneys. The selected sample comprised 6 groups of 25 subjects in each of 3 self-reported durations of daily smoke exposure for both smokers and non-smokers. All the spirometric tests (FVC, FEV1 and FMEF 25-75) were performed in the standard way recommended by the American Thoracic Society.

Variations in age, height, arm-span and weight between the three levels of exposure to domestic smoke in both the smokers and non-smokers were compared but no significant differences were found. There was a fall of mean FVC, FEV1 and FMEF 25-75, however, as duration of exposure increased. This decline was found to be statistically significant among the smokers but not among the non-smokers. Similar results were found after adjusting for age and height.

Respiratory symptoms. In Ahmedabad, western India, studies of the incidence of cough, cough with expectoration, dyspnoea and lung abnormalities found a statistically significant ($P < 0.05$) higher incidence among women cooking with smoky fuels *(9-11)*. The investigators also noted complaints by the women about the irritating effect of the smoke, particularly on the eyes.

In a three-year prospective study of clinical morbidity and air pollution in three areas of Bombay city and in one rural area nearby, Kamat et al. *(12)* found that the rural subjects were smaller in size, had lower lung function for their body stature and a higher incidence of cough and dyspnoea. Many of the respiratory symptoms exhibited by the rural population were similar to those of the moderately or severely polluted urban areas rather than the non-polluted areas. Use of wood for kitchen fuel is one of the explanations given by the authors for this finding.

In a study conducted in Ladakh, (Keith Ball, personal communication) a high prevalence of chronic respiratory symptoms was noted, particularly among women, which rises steeply with age to affect the majority of older people. About one-quarter of men and one-third of women over 50 have lung functions suggestive of obstructive airways disease, and this becomes worse in winter. Tobacco smoking has so far developed only in about 20% of the men but is virtually unseen in women. It has been suggested that domestic pollution, which is significant throughout much of the year in this high-altitude area, appears to play a part in creating this pattern.

Chronic obstructive lung disease. In a survey carried out in a housing complex in Chandigarh (India) and in a nearby village, a study was made of the records of 2 180 women aged over 20, working with different domestic fuels *(13)*. Sixty-six women (3%) had symptoms of chronic bronchitis, the highest number being in those who used the *chulla* (traditional unvented cookstove) for cooking. The cooking fuels were categorized in the following groups: I–liquefied petroleum gas (LPG); II–kerosene; III–coal; and IV–*chulla* (wood and cow dung). Five per cent of the subjects in group IV had chronic bronchitis compared to 1.5% and 1.3% in groups I and II, respectively. This difference was statistically significant ($P < 0.01$). Analysis of peak expiratory flow rate showed it to be low in subjects in group IV, but after adjusting for age and height, no difference was found between the four groups.

Hospital statistics in Nepal showed an unusually high proportion (46%) of *cor pulmonale* in hospital cardiac admissions *(14)*, indicating the need for field studies to determine the distribution and magnitude of chronic bronchitis and chronic *cor pulmonale*, and to identify the factors responsible *(15)*. Four sites were selected for this purpose: urban Kathmandu, nearby villages from Kathmandu Valley in the hills region, a village district in the plains region (terai) near India, and a district in the mountains. A survey of the prevalence of chronic bronchitis in the area of the hill villages was used to determine the required sample size in other areas. In the plains village, a simple random sampling method was used to select the sample. Two-stage random sampling was done in the urban areas and in the mountain district.

In all the study areas, houses were ill-ventilated and without chimneys. Most of the houses had only two or three rooms, but many had two floors. Cooking was done on traditional stoves in a corner of one of the ground-floor rooms in the morning and evening (the villagers take only two main meals a day). Most houses in the hills and mountains were customarily heated by means of an open fire in a fireplace known as an *ageno* dug into the floor of a ground-floor room. Members of the family sit around the *ageno* in the morning and evening to keep themselves warm. The *ageno* is also used for preparing cattle fodder in the morning and snacks for family members. Except in urban Kathmandu, there was no general industrial air pollution.

A questionnaire, modified slightly for different sites, recorded demographic information and exposure-related information such as smoking habits, location of kitchen, type of fuel used for cooking and heating and average time spent daily near the fireplace, along with the information required to diagnose chronic bronchitis according to the British Medical Research Council criteria. Emphysema and chronic *cor pulmonale* were diagnosed according to the WHO Expert Committee criteria. The individuals were classified as smokers, past smokers, or non-smokers and into various strata according to self-reported number of hours spent daily near the stove where, presumably, the highest smoke concentrations are found.

This study *(15)* found a high prevalence (crude and age-adjusted) of crude chronic bronchitis and *cor pulmonale* (10-30%). A striking feature was the similarity of rates in men and women. The difference in prevalence rate between the sexes was not statistically significant in any study area ($P > 0.10 - > 0.98$). This conflicts with most other studies, which have shown a lower prevalence rate among women. Tobacco smoking is common in both men and women in all but the urban area, where the smoking rate among women was only 14%. In all areas, however, women were light smokers (less than 10 cigarettes or equivalent per day). Heavy smoking among men was much more prevalent and the difference was statistically significant in all three rural areas ($P < 0.05 - < 0.001$) although not in urban Kathmandu. This suggests that the high prevalence of chronic bronchitis in women is primarily occupational since women engaged in cooking meals for the family are exposed for proportionately longer hours at higher concentrations of domestic smoke pollution than men. The difference in smoke

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exposure hours was significantly higher ($P < 0.001$) in women in all the study areas.

In the hill villages, a statistically significant ($P < 0.001$) positive correlation was found between prevalence of chronic bronchitis and exposure to domestic smoke pollution in both smokers and non-smokers *(Fig. 1)*. This supports earlier studies in India and Papua New Guinea *(16-19)* which suggested the possibility of a relationship between chronic bronchitis and domestic smoke pollution. The trend of increasing prevalence rates with increasing smoke exposure persisted even after elimination of the age effect *(20)*. A similar statistically significant correlation was also found in other study sites. In the mountain village, it was not possible to compare the prevalence between exposed and non-exposed groups, because everybody was exposed to domestic smoke from space heating. Unlike in other areas, however, many were exposed more than 8 hours per day. This provided an opportunity to test for an effect at longer hours of exposure. A significant correlation between bronchitis and smoke exposure was noted also beyond 8 hours of exposure among the smokers of both sexes. Hence, there seems to be a dose-response relationship between domestic smoke pollution and chronic bronchitis.

All the cases of chronic *cor pulmonale* identified in this study were complications of chronic bronchitis. Although most of the women smokers were light smokers, the study recorded similarity of prevalence of chronic *cor pulmonale* in the two sexes. This suggests that domestic smoke pollution is an important factor in producing *cor pulmonale*.

Childhood acute respiratory infections (ARI). Between 4 and 5 million children < 5 die in the world each year from ARI, mostly in developing countries. Most ARI studies have focused on the important issues of microbial causative agents, case-management with antibiotics, and effectiveness of vaccination. Research on risk factors has been judged to be of lesser importance in spite of the dominance of risk-factor reduction in the history of ARI control in the developed countries. Domestic smoke pollution has been assumed to be an important risk factor for ARI in many parts of the developing world,[1] but there have been few studies, particulary of the relationship with pneumonia, which is nearly always involved in fatal cases.

In a study carried out before 1980 in Papua New Guinea, Anderson *(21)* failed to find an effect of environmental differences, including household smoke, on acute respiratory symptoms among schoolchildren.

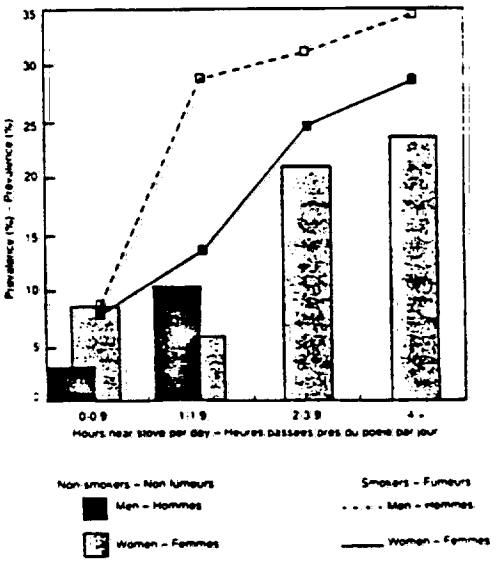
In a study of younger children in South Africa, Kossove *(22)* found that 70% of Zulu infants with respiratory symptoms lived in households with cookfire smoke, compared to 33% of a partially matched group who did not have such symptoms. This was significant at the $P < 0.005$ level, although there was no significant difference in the maternally-reported exposure times for the groups. No confounding factors were investigated.

[1] World Health Organization. *Acute respiratory infections in children*. Dossier ARI-5 of the Respiratory Infections Programme and the Programme Support Service. Geneva, 1987.

FIG. I

PREVALENCE OF CHRONIC BRONCHITIS IN NEPALESE HILL VILLAGES ACCORDING TO SELF-REPORTED DAILY TIME SPENT NEAR COOKING/HEATING STOVE, AROUND 1984 [a]

PREVALENCE DE LA BRONCHITE CHRONIQUE DANS LES VILLAGES NEPALAIS DE MONTAGNE EN FONCTION DU TEMPS PASSE PAR JOUR A PROXIMITE DU POELE (CUISINE/CHAUFFAGE), VERS 1984 [a]



[a] The strong associations are statistically significant ($p<0.001$) for all smokers and for women non smokers (20). – Une association nette est statistiquement significative ($p<0.001$) pour l'ensemble des fumeurs et pour les femmes qui ne fument pas (20).

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As part of WHO-sponsored indoor air pollution studies in Kenya and the Gambia *(23,*)*, ARI incidence in Kenyan children < 5 was monitored bi-weekly in 36 houses for 42 weeks. During this period, stationary indoor 24-hour monitoring was conducted twice in each house, for nitrogen dioxide and suspended particulates. Although respirable particulate concentrations were quite high (mean of 1.4 mg/m³), no correlation was found between ARI incidence and indoor concentrations of either pollutant, or with exposures of the children, as determined from the concentrations and time spans constructed by interviewing the mothers.

Moreover, the measured concentrations were quite homogeneously distributed among the households. Indeed, the intra-household variation between the two measurement days was greater than the inter-household variation, although households were randomly chosen from four groups stratified on the basis of house characteristics, roof type and kitchen arrangement, thought to influence ventilation, and thus indoor air quality. As the authors point out, given the apparent lack of natural variation in exposure among households, it would be quite difficult to establish smoke as a risk factor with this type of study design.

In the Gambia, on the other hand, where indoor woodsmoke levels were also high, but homogeneously distributed, there seemed to be significant differences in exposures because some young children are carried on their mother's back during cooking. Based on a multiple logistic regression, Campbell et al. *(24)* report an adjusted odds ratio of 2.8 for episodes of breathing difficulty among 280 children carried by their mothers. The only other significant risk factor was paternal smoking.

A semi-quantitative epidemiological study was conducted in Nepal by Pandey et al. *(25)*, to assess the relation between maternally-reported hours spent per day near the hearth by infants and children < 2, and episodes of life-threatening, moderate and severe ARI. In the study area, a hill region of Nepal, traditional stoves burning biomass fuels, mainly wood and crop residues, are used for cooking and heating in unventilated houses with no chimneys. The area is totally free from industrial pollution.

The first substudy was conducted during a six-month period in 1984. A statistically significant ($P < 0.01$) association was found when the exposed group was compared with the non-exposed in the two age strata i.e. < 1 year *(Fig. 2a)* and 1-2 years. In order to confirm and validate the findings, an additional three-month substudy was conducted in the same population. This substudy employed separate groups of observers to determine ARI episodes and smoke exposure times, thereby assuring a greater degree of independence in observation of the two variables. A statistically significant ($P < 0.01$) association was found in this second substudy as well *(Fig. 2b)*.

There were no obvious confounding factors that might account for these findings. Socioeconomic condition is not an important factor as more than 98% of the population live within a subsistence economy, and nearly all the houses are similar in construction. This preliminary study seems to suggest that domestic smoke pollution is a risk factor of ARI. As with all available studies, however, there were insufficient resources to fully monitor exposure, measure and correct for confounding variables, and to conduct the many expensive and time-consuming quality-control procedures needed for full-scale modern environmental epidemiology investigations.

Coal – East Asia

In China, coal is and will remain for decades the main energy source. Particulates and sulfur oxides emitted from coal combustion are two of the main urban atmospheric pollutants. In Shanghai, some 5% of total coal consumption is used for domestic cooking, making it the most important urban cooking fuel. For example, until 1987 Tianjin was the only city where all the families used gas stoves and in Beijing, only 70% of the families used gas or liquefied petroleum gas, while in Shanghai about half of the population use coal-cake stoves. Little indoor air quality research has been done in rural areas where most of the population uses crop residues and wood.

Research on indoor pollution and its health effects was initiated in China towards the end of the 1970s and over 100 papers have been published *(6)* on the subject. A series of epidemiological surveys have been carried out to evaluate the effect of indoor pollution on human health. In contrast to studies in developed countries, the gas-user group is usually considered as the unexposed control group, and the coal-user group as the exposure group.

Immunological function. The influence of indoor air pollution on immunological function was investigated in groups of primary-school students aged 10-13 exposed (or not) to coal smoke at home and at school *(26)*. Compared to the control group, the amount of SIgA in saliva of the exposure group decreased by 32.5%, and the activity of lysoenzyme by 17.3%. There were no differences in distribution of age, sex and ETS exposure between the groups (P values, all > 0.05).

Wang & Chen monitored the immunological parameters of primary-school pupils from families using different fuels for cooking.* The results were statistically significant (< 0.05) for white blood-cell count (mean reduction: 13%), saliva lysoenzyme (13%), transfer of lymphocyte (50%), IgG (29%), IgM (28%) and IgA (54%), but not in the PHA skin test.

Carboxyhaemoglobin (HbCO). The blood HbCO concentration in women using coal stoves was 2.1 ± 0.9%, compared to those using gas stoves at 1.4 ± 1.0% ($P < 0.01$). Women using coal stoves without chimneys had 4.3%, while those using chimneys had 3.0% *(27)*.

A study by Hu & Liu of 450 suburban schoolchildren < 13 near Beijing *(28)* found significantly higher HbCO levels in those living in traditional housing where pit stoves were used for heating and cooking, compared to those residing in modern buildings with stoves and chimneys. At 4.1% and 2.8%, however, both groups were high. The authors compare

* World Health Organization. *Indoor air quality in the Basse area, the Gambia.* (Document GEMS/HEALS WHO/PEP/88.3, 1988).

* Wang, J. & Chen, B. H. *[The influence of air pollution on immunological parameters of children].* Shanghai Medical University, 1987. (Graduate thesis). (In Chinese).

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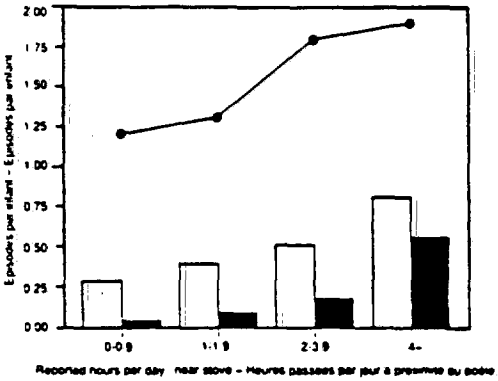
FIG. 2

ACUTE RESPIRATORY INFECTIONS IN INFANTS (0-1) IN THE HILL REGION OF NEPAL LISTED BY SEVERITY AND MATERNALLY REPORTED DAILY TIME NEAR STOVE [a]

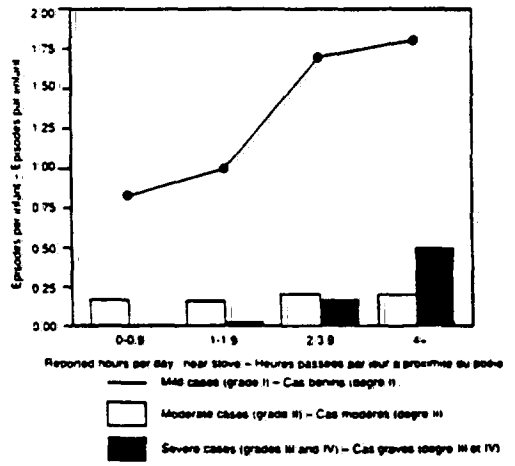
INFECTIONS RESPIRATOIRES AIGUËS CHEZ LES NOURRISSONS (0-1 AN) DANS LA RÉGION DE MONTAGNE DU NEPAL, CLASSÉES SELON LA GRAVITÉ ET SELON LE TEMPS PASSÉ PRÈS DU POÊLE CHAQUE JOUR AU DIRE DE LA MÈRE [a]

A. Based on six months' data collected in 1984 (233 infants) – Sur la base des données recueillies en 1984 sur une période de six mois (233 nourrissons)



Reported hours per day near stove – Heures passées par jour à proximité du poêle

B. Based on three months' data collected in 1989, with the same population (247 infants) but with separate teams diagnosing ARI and determining exposure – Sur la base des données recueillies en 1989 sur une période de trois mois dans la même population (247 nourrissons), des équipes distinctes étant chargées de diagnostiquer les IRA et de déterminer l'exposition



[a] The trends are significant in both cases (P) – Les tendances sont significatives dans les deux cas (P)

these results with an earlier urban study,[1] where HbCO levels of 4.3%, 3.0% and 1.1% were found for residents in homes heated by stoves without flues, by stoves with flues, and by circulating hot water respectively. This study also found other effects. There were significant differences in the incidence of lower respiratory diseases among girls ($RR = 3$, $p < 0.05$) but not for boys nor for upper respiratory diseases. Small or non-significant differences were found for immune and eye responses and lung function, after correcting for height, age, weight, family income and parental smoking *(28)*.

[1] Chang X. M. *[An epidemiological study on indoor air pollution]*. Second National Conference on Environmental Health, October 1984, Nanjing. (In Chinese).

Although small-scale combustion of all coal and biomass fuel is often associated with high CO emissions, poor combustion of all unprocessed biomass and high-volatile coals also emits large amounts of hydrocarbon aerosol and gas, e.g. aldehydes. Although these may have long-term health effects because of the intense irritation they cause, they act in the short term to warn when CO concentrations approach acutely toxic levels. In other words, it is extremely rare for someone to die from acute CO poisoning from such fuels. Even though measured CO concentrations can sometimes approach dangerous levels, the irritation due to hydrocarbons will awaken householders and prompt them to escape or open a window *(4)*.

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Unfortunately, this is not the case with the three principal low-volatile solid fuels: charcoal, naturally low-volatile coal such as anthracite, and processed (devolatilized) coal. These may release no more CO than the high-volatile solid fuels, but they do so with little of the irritating hydrocarbons that provide warning. As a result apparently, hundreds if not thousands of people die every year in northern China, Korea, the Islamic Republic of Iran and other developing countries where overnight space heating is provided by such fuels (mainly coal), along with excessive leakage of combustion gases into living areas, compounded by poor household ventilation. A study in Korea, for example, has shown a strong seasonal variation in hospital admissions for CO poisoning, peaking during the cold season where heating is used *(29)*. Mortality is not the only effect–high, but sublethal, exposures can cause serious poisoning.

Lung function. Li & Hong[a] monitored the lung functions (FVC, FEV1, FEV1%) of 213 women aged 50-70 years, including 167 women using coal and 46 using gas for cooking. Even after adjustment for potential confounding factors, i.e. age, body weight, height and ETS, there was a statistically significant difference between the coal group and the gas group in all lung functions tested.

In another study, the FEV1/FVC of persons using coal stoves was lower than those using gas stoves, while the reverse relationship was found for MEF25, MEF50 and MEF75. This was possibly due to higher NOx concentrations in homes using gas.

In Xuanwei County, Yunnan Province (southern China), the airway resistance of farmers and schoolchildren in homes where poor-grade bituminous coal was used for cooking was higher than in homes where wood and straw were used for cooking ($P < 0.001$) *(30)*.

Respiratory symptoms and non-cancer respiratory diseases. There seems to be an increase in respiratory symptoms and prevalence of respiratory diseases in coal-using families. A study[c] was conducted in two areas of Shanghai with populations of about 77 000 and 17 000 respectively. Two samples were selected, using cluster sampling: 1 316 using coal-cake stoves and 721 using gas stoves. The respiratory symptoms and prevalence of respiratory diseases were found to be 79% and 44%, respectively, for people using coal stoves and gas stoves ($P < 0.05$).

The prevalence of respiratory diseases among housewives aged 40-65 are 50% and 40%, respectively, for coal-using homes and gas-using homes, where $P < 0.05$, and relative risk for coal-using housewives is 1.9 *(28)*. The prevalence of common cold among persons using stoves with or without chimneys were 22% and 52% respectively; RR = 2.0 (without chimney), attributable risk = 25% *(31)*. The prevalence of chronic bronchitis, emphysema, cough, productive cough and breathlessness in women using coal stoves were significantly higher than among those using gas stoves. There were no significant differences in the prevalence of coronary heart disease, hypertension and a tight feeling in the chest between the coal- and gas-using groups.[c]

Another study,[c] carried out in Shanghai on 12 037 people, using the American Thoracic Society DLD-78 questionnaire, found that in areas where atmospheric pollution was light, the prevalence of COLD was 9.6% in the gas-user group and 15.6% in the coal-user group. In heavily-polluted areas, these prevalences were 12.8% and 17.3%, respectively. Multivariate analysis indicated that indoor air pollution had a stronger impact than outdoor air pollution.

Another survey of respiratory symptoms and diseases was carried out among retired women and nonemployed women aged 45 years and over *(32)*. Of the 393 women who responded to the questionnaire, 186 used gas for cooking and 207 coal. Indoor pollutant concentrations typically found in each type of home were determined, based on small representative samples. The results are listed in *Table 1*.

In order to determine whether factors other than indoor pollution (such as age, living standard, education, ETS, kitchen style and living space per person) were important influences, a multifactor logistic regression analysis was conducted. The result showed that domestic smoke was an important contributing factor to chronic bronchitis, emphysema,

[a] Li, L. & Hong, C. J. *[Kitchen air pollution and its health effects]* Shanghai Medical University, 1988 (Graduate thesis) (In Chinese).

Lin, H. S. et al. *[Relation of air pollution and human health in a higher density residential area of Shanghai]*. Symposium on Environmental Health, Taiyuan, 1983. (In Chinese).

[c] Hong, C. J. et al. *[Studies on air pollution and its impact on health in Shanghai]*. Shanghai Medical University, 1989. (In Chinese).

TABLE 1. PREVALENCE OF RESPIRATORY SYMPTOMS AND DISEASES IN WOMEN USING DIFFERENT FUELS FOR COOKING, 1985

TABLEAU 1. PRÉVALENCE DES SYMPTÔMES ET MALADIES RESPIRATOIRES CHEZ LES FEMMES UTILISANT DIFFÉRENTS TYPES DE COMBUSTIBLES POUR LA CUISINE, 1985

Disease or symptom Maladie ou symptôme	Gas user group (186 cases) Groupe utilisant le gaz (186 cas) Number — Nombre	 %	Coal user group (207 cases) Groupe utilisant le charbon (207 cas) Number — Nombre	 %	χ^2(M—H) Number — Nombre	P %
Asthma — Asthme	6	3.3	15	7.2	2.2	>0.05
Chronic bronchitis — Bronchite chronique	22	11.8	51	24.6	7.5	<0.01
Bronchodilatation	3	1.64	13	6.23	4.6	<0.05
Emphysema — Emphysème	4	2.15	21	10.1	7.3	<0.01
Coronary heart disease — Cardiopathie coronarienne	27	14.5	25	12.1	0.69	>0.05
Hypertension	60	32.3	66	31.3	0.03	>0.05
Cough — Toux	33	17.7	83	40.1	19.1	<0.01
Expectoration	24	12.9	53	25.6	7.5	<0.01
Chest tightness — Gêne respiratoire	55	29.6	77	37.2	2.1	>0.05
Shortness of breath — Essoufflement	18	9.68	53	25.6	13.4	<0.001

Source: Reference (32) — Référence (32).

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bronchodilatation, cough, expectoration and shortness of breath. These conditions were 1.8-4.5 times more common among the group exposed to coal smoke. No significant difference was found for coronary heart disease.

In Hong Kong, Koo et al. *(33)* found small (10-20%) but statistically significant differences in nitrogen dioxide exposure levels as well as reported respiratory symptoms (allergic rhinitis and bronchitis) among non-smoking mothers in homes using piped gas (lower exposure) for cooking, compared to those using kerosene or bottled gas. A similar effect was found for incense-burning and kitchen ventilation, but not for mosquito coils or ETS. No effect was found in children.

Cancer. Although the lung-cancer risks of occupational exposures as well as active smoking, and to a lesser extent ETS, have been extensively documented, the relation between lung cancer and ambient air pollution remains uncertain. Indoor pollution, however, is now starting to be linked to lung cancer, especially among women cooking over coal-fired stoves, although their level of cigarette smoking and occupational exposure is much lower than men's.

Xu et al. *(34)* analysed female lung-cancer prevalence in 16 Chinese metropolitan areas, each with a population over 500 000 and located at various latitudes. They found that the correlation coefficients between female lung-cancer prevalence and latitude were statistically significant. The higher the latitude, the higher the lung cancer prevalence.

Yang et al.* compared several factors with the high and low lung-cancer prevalence regions in Wuhan (standardized rates: 26 vs. 12 per 100 000) to find that there were significant differences in stove types and density, sulfur dioxide and nitrogen oxides, but not for carbon monoxide.

In Guangzhou, there were 349 housewives among 1 243 female lung-cancer deaths *(35)*. These women (28%) had no previous occupational exposure, 40% of them were non-smokers, and none seemed to be exposed to significant outdoor air pollution. The epidemiological survey showed that female lung-cancer occurrence was related to exposure to coal combustion and cooking *(36)*. The investigators monitored kitchens for suspended particulates, deposited dust, and benzo(a)pyrene in deposited dust. They found (as expected) that concentrations were much higher in kitchens using coal compared to those using liquefied petroleum gas for cooking.

Based on a case-control analysis of 662 deaths (446 males and 216 females), the lung-cancer odds ratio (OR) of smoking and cooking was analysed and is presented in *Table 2 (36)*. Exposure to cooking was found to be an important contributing factor to female lung cancer, but not to male lung cancer. The combination of smoking and cooking exposure has a synergistic effect on the prevalence of lung cancer in both males and females.

Another matched case-control study and measurement of indoor air pollution was carried out in a northern Chinese city (Harbin) to analyse risk factors for female lung adenocarcinoma *(37)*. The results showed that a high coal-consumption index (HCCI, OR = 10.6), indoor smog pollution in winter (OR = 15.2) and low ceiling height of the living room (OR = 12.5) were the main risk factors for female lung adenocarcinoma. It was further confirmed by indoor air monitoring that the average air concentrations of total suspended particulates (TSP) and benzo(a)pyrene in bedrooms in winter were 4.4 and 27 times higher than the respective maximum allowable air concentrations in China. No significant correlation was found between female lung adenocarcinoma, and cigarette smoking and ETS.

TABLE 2. LUNG-CANCER ODDS RATIO (OR) OF SMOKING AND COOKING — CASE-CONTROL ANALYSIS, 662 PAIRS, 1988

TABLEAU 2. ODDS RATIO (OR) DE CANCER DU POUMON PAR EXPOSITION AU TABAC ET AUX FUMÉES DE CUISINE — ANALYSE CAS-TÉMOINS, 662 PAIRES, 1985

	M OR	P	F OR	P
(1) S+NS+E+NE[a]	1.0		1.0	
(2) NS+NE	0.31	>0.05	0.31	>0.05
(3) S+NE	4.4	<0.01	0.6	>0.05
(4) NS+E	1.4	>0.05	3.1	<0.05
(5) S+E	4.2	<0.01	5.8	<0.01

[a] S = smokers — fumeurs.
NS = non-smokers — non-fumeurs.
E = exposed (coal stove) — exposés (cuisinière à charbon)
NE = non-exposed (gas stove) — non exposés (cuisinière à gaz)
Source: Reference (36) — Référence (36)

In another Xuanwei study, the standardized lung-cancer mortality in 1973-1975 was 26 per 100 000, higher than the average urban lung-cancer mortality in China. In Xuanwei, lung-cancer prevalence was different in various regions, the highest being over 150 per 100 000, while the lowest was under 1 per 100 000, a difference of about a factor of 200. Although rare today, in the recent past high-tar bituminous coal burned in open pits was the main domestic fuel used in high lung-cancer prevalence regions, while anthracite coal and wood were used in low-prevalence regions. The prevalence of lung cancer in farmers was higher than among people in other occupations and there was little difference between sexes. This evidence suggests the presence of a strong carcinogenic factor linked to lung cancer in nonemployed women *(38)*. Research involving indoor air monitoring, epidemiological studies and animal exposure tests *in situ* have been conducted by the Chinese Academy of Preventive Medical Sciences and local public health and anti-epidemic stations with assistance from the United States Environmental Protection Agency *(39, 40)*.

In Hong Kong, however, no significant association was found between lung cancer and cooking fuels *(41)* or ETS *(42)*. The indoor-pollutant concentrations were much less than those found in the above-mentioned lung-cancer studies in China. Although there have been reports linking domestic smoke with the high rates of nasopharyngeal cancer among southern Chinese populations *(43, 44)* and in other groups, e.g. Kenya *(45, 46)*, most reviews have concluded that the risk must be small or non-existent compared to risk factors such as diet *(47)*.

Fluorosis. Increased fluorosis induced by high concentrations of fluoride in indoor air and food originating from coal combustion has been reported recently *(48-51)*. In the suburbs of Xiangtan (Hunan Province) the fluoride concentration in drinking-water was less than 1 mg/litre, but in coal it was

* Yang, X. et al. *[The relation of indoor air pollution and human health — a primary study]*. Workshop on Chinese environmental health, 1983. (In Chinese).

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190-330 mg/kg. Fluoride concentration originating from coal combustion was 0.018-0.066 mg/m³ in indoor air and 1.9-3.3 mg/kg in vegetables. The prevalence of dental fluorosis there was as high as 35% in residents of all ages. In a neighbouring area, the prevalence of dental fluorosis in a control group cooking with wood was only 4.9% *(48)*.

In the suburb of Luoyang (Henan Province) the fluoride concentration of coal was 370-640 mg/kg, and the indoor-air fluoride concentration was measured at 0.016 mg/m³. The vegetable and grain fluoride concentration was 0.95-3.4 mg/kg. This increased to 2.7-14 mg/kg after a half-year storage period indoors. There were 1 486 persons suffering from fluorosis among 2 246 persons aged over 6. The prevalence rate was 66% *(49)*. Increased prevalence of fluorosis due to coal combustion in residents has also been found in Xianwen (Sichuan Province), Ankang (Shanxi Province), Benxi (Liaoning Province) and Huanggang (Hubei Province).

Stroke. A group of 957 men were followed for 12 years in a study of risk factors for heart disease and stroke carried out in Shanghai *(52)*. During the study period, 24 subjects died. In addition to high blood pressure, age and smoking, the study found exposure to household coal smoke to be a significant risk factor. A dose-response relationship was found with the relative risk of heavy exposure (only coal use) of nearly 11, after correction for the other major risk factors. The slight-exposure groups (using both gas and coal) had a relative risk of nearly 4.

Conclusion

Available evidence in the developing world would seem to argue strongly that indoor air pollution from cook-fire smoke is a risk factor for chronic lung disease in adults, particularly women, and acute respiratory disease in young children. In addition, coal smoke may be an important risk factor for lung cancer in women. The total number of people exposed to high concentrations of smoke is likely to be several hundred million.

However, too few resources have been allocated to such studies for it to be possible to quantify these effects. Such efforts are needed, however, in order to determine the effectiveness of smoke-exposure reduction measures in comparison with other approaches for preventing or mitigating these diseases.

In particular, there is a need to link detailed epidemiological study designs using internationally accepted diagnostic procedures with detailed and systematic exposure determinations. This is not easy to do with cancer and chronic obstructive lung disease, since exposure histories going back several decades must be established.

One of the highest priorities for indoor air pollution epidemiology is to initiate a study of the risk factors for ARI, because of its importance as a cause of early childhood morbidity and mortality in many developing countries, and in view of the high indoor exposures that seem to prevail in many areas. A longitudinal intervention study lasting at least two years and including all seasons before and after intervention would most likely lead to results that are scientifically sound and useful for designing large-scale intervention programmes *(53)*.

A growing trend among those concerned with environmental epidemiology is the realization that, in order to understand the impact of pollution on health, it is necessary to monitor dwelling places rather than just the ambient environment. Total exposure assessment is the term for such efforts, which are beginning to reveal important sources and control measures different from those on which past efforts have focused *(4)*. Indeed, from a global standpoint, the present balance of research, monitoring and control efforts in air pollution should perhaps be shifted towards households using unprocessed solid fuels, which is where the largest number of susceptible persons can be found.

SUMMARY

Of the four principal categories of indoor pollution (combustion products, chemicals, radon and biologicals), research in developing countries has focused on combustion-generated pollutants, and principally those from solid-fuel-fired cooking and heating stoves. Such stoves are used in more than half the world's households and have been shown in many locations to produce high indoor concentrations of particulates, carbon monoxide and other combustion-related pollutants. Although the proportion of all such household stoves that are used in poorly ventilated situations is uncertain, the total population exposed to excessive concentrations is potentially high, probably several hundred million.

A number of studies were carried out in the 1980s to discover the health effects of such stove exposures. The majority of such studies were done in South Asia in homes burning biomass fuels or in China with coal-burning homes, although a sprinkling of studies examining biomass-burning have been done in Oceania, Latin America and Africa.

Of the health effects that might be expected from such exposures, little, if any, work seems to have been done on low birthweight and eye problems, although there are anecdotal accounts making the connection. Decreased lung function has been noted in Nepali women reporting more time spent near the stove as it has for Chinese women using coal stoves as compared to those using gas stoves. Respiratory distress symptoms have been associated with use of smoky fuels in West India, Ladakh and in several Chinese studies among different age groups, some with large population samples. Acute respiratory infection in children, one of the chief causes of infant and childhood mortality, has been associated with Nepali household-smoke exposures.

Studies of chronic disease endpoints are difficult because of the need to construct exposure histories over long periods. Nevertheless, chronic obstructive lung disease has been associated with the daily time spent near the stove for Nepali women and found to be elevated among coal-stove users compared to

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gas-stove users in Shanghai. In contrast to early reports, there seems to be little or no risk of nasopharyngeal cancer from cookstove smoke. Several studies in China, however, have found smoke to be a strong risk factor for lung cancer among non-smoking women. In addition, severe fluorosis has been observed in several parts of China where coal fluoride levels are high.

The high indoor concentrations and the potentially large (also poor and thus vulnerable) populations at risk, argue for more resources to be devoted to epidemiological studies of large numbers of exposed populations, using appropriate quality-control measures in order to generate reliable quantitative dose-response information. In the meantime, however, enough is known to warrant household, community and government efforts to reduce exposures through education and introduction of improved stoves, cleaner fuels and enhanced ventilation.

RÉSUMÉ

Pollution de l'air à l'intérieur des habitations dans les pays en développement

Des quatre principaux types de pollution à l'intérieur des habitations (produits de combustion, substances chimiques, radon et substances biologiques), la recherche dans les pays en développement a privilégié les produits de combustion et notamment les polluants résultant de l'utilisation de combustibles solides pour la cuisson et le chauffage. Les poêles incriminés sont en service dans plus de la moitié des habitations du monde et il a été prouvé en de nombreux endroits qu'ils étaient à l'origine de concentrations élevées de matières particulaires, d'oxyde de carbone et d'autres polluants liés à la combustion. Bien que l'on ne connaisse pas avec précision la proportion de poêles ainsi utilisés dans des locaux mal aérés, le nombre total de personnes exposées à des concentrations excessives de polluants est élevé, probablement plusieurs centaines de millions.

Dans le courant des années 80, plusieurs études ont été consacrées aux effets sur la santé de l'exposition à ces produits de combustion. La plupart ont été conduites en Asie méridionale dans des habitations où sont utilisés des combustibles tirés de la biomasse ou en Chine là où l'on utilise du charbon, bien que certaines études sur l'utilisation de la biomasse aient été faites en Océanie, en Amérique latine et en Afrique.

Parmi les effets de ce type de pollution qui peuvent être redoutés, il semble que l'on n'ait pratiquement pas ou pas du tout étudié l'insuffisance pondérale à la naissance et les problèmes ophtalmologiques, bien que certains comptes rendus anecdotiques fassent la relation entre ces problèmes et ce type de pollution. Une diminution de la fonction pulmonaire a été relevée chez des femmes népalaises ayant signalé passer beaucoup de temps auprès du poêle ainsi que chez des femmes chinoises qui utilisent des cuisinières à charbon par rapport à celles qui utilisent des cuisinières à gaz. Des symptômes de détresse respiratoire ont été associés à l'utilisation de combustibles produisant de la fumée dans l'ouest de l'Inde, au Ladakh et à l'issue de plusieurs études chinoises portant sur différents groupes d'âge, certaines auprès d'échantillons importants de population. Des cas d'infections respiratoires aiguës chez les enfants, l'une des principales causes de mortalité infanto-juvénile, ont été associés à l'exposition à la fumée dans des habitations népalaises, d'après le temps passé par les enfants auprès des poêles.

Les études sur les maladies chroniques sont difficiles car il est nécessaire d'établir des antécédents d'exposition sur de longues périodes. Néanmoins, la maladie pulmonaire obstructive chronique a été associée au temps passé chaque jour auprès du poêle pour des femmes népalaises et son taux d'incidence a été jugé élevé parmi les utilisatrices de poêles à charbon comparé aux utilisatrices de poêles à gaz à Shanghai. Contrairement à ce qui avait été précédemment indiqué, la fumée dégagée par les cuisinières ne présente, semble-t-il, que peu de risque de cancer du rhino-pharynx. Toutefois, plusieurs études menées en Chine ont montré que la fumée était un facteur de risque important pour le cancer du poumon chez les femmes non-fumeuses. En outre, des cas graves de fluorose ont été observés dans plusieurs regions de Chine où les taux de fluorure dans le charbon sont élevés.

Les concentrations élevées de polluants à l'intérieur des habitations et l'importance des populations exposées (également pauvres, donc vulnérables) justifient que des ressources accrues soient consacrées à des études épidémiologiques d'échantillons importants de population en prenant les mesures de contrôle de la qualité nécessaires à l'obtention de données quantitatives fiables sur les rapports dose-réponse. Cela étant, ce que l'on sait devrait déjà suffire à inciter les ménages, les communautés et les gouvernements à redoubler d'efforts pour réduire l'exposition à ces types de pollution, par l'éducation et l'introduction de poêles améliorés, de combustibles plus propres et de meilleurs systèmes d'aération.

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